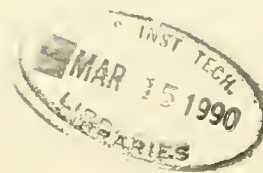WORKING PAPER
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INTERFIRM COLLABORATION IN THE DEVELOPMENT OF
NEW PRODUCTION TECHNOLOGIES:
LOOSE TIES AND FLUID PARTNERSHIPS

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Abstract

Existing research suggests that effective interfirm collaboration in the development of new process technologies involves close, dyadic relationships between users and suppliers. Shared goals, common assumptions, and long term relationships are salient features of the model. This paper develops an alternative, fluid model of interfirm collaboration involving multiple weak linkages among organizations with divergent goals and interests. Important characteristics of the fluid model are multi-stranded network patterns, reconstitutive problem solving processes, and the dominance of politics in interorganizational relations. These characteristics are proposed to be important under turbulent conditions, when technologies are shifting in fundamental ways and manufacturing companies face ill-structured questions and ill-defined environments.

Introduction: The Need for Cooperation Between Technology Source and User

Evidence is accumulating that cooperation between users and builders of manufacturing equipment and systems is a critical component in successful technology-based competition in the manufacturing sector. Several studies have demonstrated the economic and innovation benefits of sharing information about user needs and solution options during new process development. Von Hippel (1977, 1988) and others (e.g. Shaw, 1985) have demonstrated that the concepts behind successful process equipment innovations frequently originate with leading user firms, who then pass information about needs and even working prototypes to specialized equipment builders. In a study of Japanese semiconductor manufacturers, Mishina (1989) showed that shared knowhow development between competent chip producers and their equipment suppliers benefitted both the producers and the industry as a whole. Cooperation between users and builders of new process equipment has also been shown to contribute to successful implementation of new manufacturing technology in the factory (Tyre and Hauptman, 1989; Leonard-Barton, 1988, Ettlie and Rubenstein, 1980).

Further, there are persuasive reasons why cooperative process development efforts will become even more important in the future. These include greater variety and complexity of process technologies, increasing rates of change in many product markets, and the competitive demands of a global arena where major players already use various forms of interfirm cooperation as a significant competitive weapon (Westney, 1988). It is increasingly unlikely that even the most advanced firms in most industries

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will have the capabilities to develop all their new process requirements in-house, or will be able to fill in the gaps with existing off-the-shelf equipment offerings.

Despite the importance of interfirm collaboration in new process development, our understanding of how such linkages work and how to manage them is limited. Available evidence suggests that U.S. firms have not learned to use cooperative process development as an effective competitive weapon. Instead, the story of a downward spiral of mutual distrust and diminishing technological prowess has been documented in a number of key industries, including semiconductors (von Hippel, 1988: 121; Hof and Gross, 1989) machine tools, textiles, and steel (Dertouzos et al., 1989). A number of historical, structural, and cultural factors have been suggested for this failure. In this paper, I suggest that the underlying conceptual models of "cooperative development" offered in the literature are insufficient for guiding or understanding technological change in all circumstances. This paper examines the existing model of cooperation and points out some of the problems it contains. The paper further proposes an alternate model of interfirm collaboration based on "loose ties" or fluid partnerships. The fluid model, it is argued, may be important for managing new process development when technologies undergo rapid and fundamental change. The objectives of the paper are both to explore the problem of interfirm cooperation in developing new production technologies, and to illuminate the more fundamental problems of organization design and organization boundaries under turbulent environmental conditions.

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The Traditional Model: User-Supplier Interaction in Successful Technological Innovation

A recent wave of popular and academic literature suggests that when technological change and innovation is a significant basis of industry competition, the ability to build strong, durable, and cooperative relationships between firms is a critical source of advantage. Two themes characterize most of this research. The first is an emphasis on dyadic relationships (e.g. Van de Ven & Walker, 1984). While a single firm may interact with a number of suppliers and a number of customers, the traditional model describes these linkages in terms of individual pairwise relationships. The second major theme of recent research is the central role of interorganizational trust or consensus in successful cooperative relationships (e.g. O'Toole et al., 1972; Dertouzos et al., 1989). Much of the research has explored the cultural, managerial, and human problems of building and maintaining a smooth and open flow of communication in pairwise relationships.

An important aspect of what I call the traditional model is that collaboration between suppliers and users in the innovation process requires mutual commitment, openness, and interpersonal relationships developed over long association. In an influential study, the MIT Productivity Commission emphasizes "the paramount significance of strong and durable relations with suppliers and customers." They argue that "Companies should...promote business relationships based on mutual trust and the prospects of continued business transactions over the long term" (Dertouzos et al., 1989).

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In its most popular version, the traditional cooperative model is atheoretical and intended to be intensely practical. It centers on the imperative, "Get close to your customer." Peters and Waterman (1982), for instance, maintain that "no existing management theory helps much in explaining the role of the customer in the excellent company" (p. 156-7). Rather, they argue, the key is that "excellent companies really are close to their customers" (p. 156). "Most of their real innovation comes from the market" (p. 193).

In fact, however, the user-supplier interaction and its role in the innovation process has received considerable scholarly investigation. The notion that "market-pull", or customer demand for a new technology, is a significant force for innovation is well-accepted and well-documented (e.g. Myers and Marquis, 1969). Further, the importance of understanding user needs by maintaining interpersonal contact with users, regardless of whether the customer has a specific solution in mind, has also been well documented (e.g. Rothwell, 1977; De Meyer, 1983).

Moreover, research has begun to unravel the multiple forms of user-supplier interaction, and to identify the factors determining the appropriate mode of interaction between them. In an important set of studies, Eric von Hippel documented the multiple ways in which user needs are transferred to suppliers in various industries (von Hippel, 1976; 1977). He found that in certain industries the majority of successful innovations could be attributed to "lead-users" of particular process technologies. In these user-lead innovations, users who were best positioned to benefit from advanced processes or equipment not only recognized an unmet need, but also devised,

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built, and tested new solutions in the form of prototype devices which equipment builders then adopted, refined and manufactured.

Building on these findings, other studies have argued that in many cases the innovation process cannot be said to be dominated by either user or supplier, but rather involves "multiple and continuous interactions" between user and builder throughout the project (Shaw, 1985: 283). Matching user needs and technological solutions is seldom simple. An "innovation" often comprises a number of components, ideas, and alternatives; the nature of the innovation is often dependent on how it is used. Similarly user needs, or even a single user's needs, are not a static fact but are changed by exposure to new ideas, possibilities, and problems. The innovation process itself can be conceived as a compilation of subprocesses over which a technology moves from a general concept to a specific set of technical inputs and organizational behaviors in the user environment (Eveland, Rogers and Klepper, 1977). To be successful, researchers have argued that the process requires "mutual adaptation" (Leonard-Barton, 1988) or "mutually reinforcing collaboration" (Morphet, 1978) between producer and user. Such collaboration also feeds into future development efforts, providing the builder with new insights as use reveals new needs and possibilities (Gardiner and Rothwell, 1985).

Several factors seem to determine whether the innovation process -- from conception through introduction -- can be neatly split between user and builder, or whether "multiple and continuous" collaboration will be necessary. First, fundamentally new technology or major improvements to existing technology involve higher levels of uncertainty regarding the technology and its implications for both user and builder than do minor changes, and

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therefore require closer and more continuous interaction (Gardiner and Rothwell, 1985; Shaw, 1985). Second, intensive interaction is necessary when potential users require assessment and trial of the technology prior to introduction, such as when change is irreversible or has major implications for the user's production process (Rogers, 1983). The same is true when knowledge about the environment and conditions of use are not fully understood by the builder, but reside in user-experts (Shaw, 1985). When such knowledge is tacit, or not readily available even to user-experts, the need for mutual interaction and experimentation is especially acute. Finally, characteristics of the product design itself partly determine the need for close user-builder interaction. In some products (such as software packages) designers can introduce features that facilitate modification by the users as they gain familiarity and experience (von Hippel and Finkelstein, 1978); in other kinds of products (e.g. chemical processing plants; emergency medical devices) such user-design is less feasible.

User-Builder Interaction Patterns in the Development of New Manufacturing Technologies

The above factors suggest why close collaboration between user and builder is often necessary for successful process innovation. They also suggest why collaboration can be difficult. In developing and introducing new manufacturing technologies, the innovation process is "intimately tied to and constrained by the current manufacturing system" (Kazanjian and Drazin, 1986: 91). In a modern manufacturing plant that existing system can be overwhelmingly complex. It is subject to unpredictable and often unidentifiable disturbances. A single factory involves technical, organizational, intellectual, and economic subsystems in an integrated web.

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Knowledge of the system is therefore incomplete, diffuse, and difficult to transfer to an equipment developer or even to a single expert in the user organization. Further, because of the interconnected nature of the manufacturing environment, technological change can have large, unpredictable, and potentially very expensive implications for the user. Therefore preliminary assessment and testing are essential. However, for the very reasons given above, the appropriate criteria and the procedures for effective pretesting often cannot be specified. It is often impossible to replicate or simulate realistic conditions of use in a test situation.

Under these circumstances, research indicates that intensive interaction between users and suppliers of new process technologies should be a critical ingredient in successful innovation in the manufacturing environment. Indeed, several studies suggest that such collaboration during development and introduction is associated with project success on a number of dimensions (Tyre 1990; Leonard-Barton, 1988, Ettlie and Rubenstein, 1980). Many of these research results support the traditional model of interfirm cooperation. They suggest that manufacturing firms need to build strong, lasting, and close ties not only with their final customers and component suppliers, but also with their suppliers of capital equipment and process technology. As in other versions of the traditional model, the research suggests that building such interorganizational relationships takes time; trust develops from multiple satisfactory transactions and communications. An important factor in successful technological innovation in manufacturing, it is argued, is the history of the relationship between the builder and user of new manufacturing technologies (Ettlie and Rubenstien, 1980; Rogers, 1983).

Indeed, where innovation is relatively continuous, with each new product or process idea building on the existing generation, the traditional model probably represents an effective mode of interfirm organization for process innovation. When the direction of technological change is relatively continuous -- even if the size of the change is large or the technical problem is highly complex -- it is likely that the factors that made the partnership effective in serving today's needs will also facilitate continued innovation. The mix of skills, capabilities, resources, and organizational goals should be directly applicable to the new set of problems. The language and communication channels developed over the period of association will facilitate problem solving and task coordination. Moreover, the long-lived nature of the relationship should increase the joint innovative capacity of the firms by strengthening mutual understanding of needs and capabilities and creating a base of mutual trust for sharing new ideas.

Such existing relationships are built around dominant technologies (Abernathy and Clark, 1985) and interorganizational configurations (Hamlett, 1984). As Weiss and Birnbaum (1989) point out, both technological exploration and organizational accommodation occur according to established ground rules. Established relationships "link users and inventors in a long-term, focused process. The resulting incremental changes in technology are oriented toward common long-term objectives and can be viewed as progressive technological change" (p. 1019).

However, in many cases technological change represents a shift away from the existing "dominant design". In these cases, innovation introduces new kinds of technologies or new ways of using and organizing existing

technical capabilities. Such changes obsolete existing assumptions, and require the development of new modes of problem solving and even new sets of goals and means of measuring progress (Normann, 1971). Technological shifts create both considerable uncertainty about how to overcome technical problems, as well as ambiguity regarding the choice of problems to work on, solution methodologies to apply, and appropriate criteria for success[1].

The implications of technological shifts derive from the nature of the change, not its size. While some innovations build in a fairly systematic way on existing technical disciplines, firm capabilities, and organizational assumptions, others obsolete existing competencies (Abernathy and Clark, 1985; Tushman and Anderson, 1986). In the former case, problem solving can be based on a reasonably systematic, well-understood set of rules; in the latter, new approaches to idea generation and problem solving must be found or created (March and Simon, 1958; Weiss and Birnbaum, 1989).

The meaning and special significance of technological shifts in manufacturing are illustrated by recent examples. For instance, researchers have pointed out that the salient aspect of microprocessor-based flexible manufacturing systems is not only the levels of technical diversity and sophistication involved, but also the shift in operating skills, managerial assumptions, and organizational practices required (Jaikumar, 1986; Gerwin, 1981; 1988).

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[1] The distinction between "complex" and "ambiguous" problems in technological process change is discussed in detail in Tyre (1990). The discussion there, in turn, draws on distinctions made in Perrow (1967), Abernathy and Clark (1985), and Tushman and Anderson (1986).

As Normann (1971) points out, technical shifts or "reorientations" are significant because they require changes in organizational systems and subsystems: they call for new kinds of specialist knowledge, new goals and values, new power relations, and changes in the organization's external domain. This suggests that when organizations face technological shifts, the traditional model of user-builder cooperation is insufficient in power or scope. The model describes a set of interfirm relationships which are too narrow, too close, and too comfortable to contribute to the innovation process. Further, the model itself is limited in power by its static nature and by its underlying assumptions regarding the source of the firm's competitive advantage.

Problems with the Traditional Model of Interorganizational Cooperation

Problem #1: Too Narrow. The traditional model of organizational cooperation generally assumes a simple dyadic relationship either between the supplier and its customer, or between the supplier and its customers as a group. There are several problems with this assumption. First, there is seldom "a" customer (user) or group, but rather a diverse mix of users with very different needs, capabilities, patterns of use, etc. As Eric von Hippel (1976; 1982) points out, different kinds of users provide equipment suppliers with different new product insights. Itami (1987) further notes that "getting close" requires different kinds of activities and investments depending on the specific customer segment addressed.

Further, in dealing with technological shifts it is often difficult or impossible to identify necessary inputs and the customers or suppliers that

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offer them. In many such situations, critical suppliers or customers may lie outside of the firm's current domain, or may be linked only indirectly to the organization. As the organization's role or activities change, so the set of outside organizations to which it is directly linked must also change (Evan, 1966). Terreberry (1968) notes that when an organization's environment becomes turbulent, its external interconnectedness and transactional interdependencies change in unpredictable ways. Small clusters of organizations sharing common values are replaced by larger, highly diverse and interdependent systems of specialized organizations (Terreberry, 1968: 601).

This phenomenon is illustrated by the adoption of basic oxygen furnace (BOF) technology in the steel industry. Early adopters of the technology faced a highly ambiguous set of problems. There were no existing means for analyzing the technology and its potential impacts. Further, managers did not know who should participate in decisions or even which players should be interested and involved (Lynn, 1982). The decision and problem solving processes surrounding the innovation resembled "organized anarchies" (Cyert and March, 1963; March, Cohen and Olsen, 1972); they involved "a confluence of changing streams of problems, solutions, participants, and choice opportunities" (Lynn, 1982: 6). Key decisions were determined by external developments, and critical resources were located outside of the steel-making firms or their traditional partners.

Further, when technological change involves significant ambiguity, it is impossible to predict the skills, knowledge, or components that will be required to develop and use the new technology. These are discovered in

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the process of action; the specific partners and even the forms of cooperation called for may be very different from existing linkages. This was the case in the machine tool industry. The most critical problem posed by the advent of CNC technology for existing machine tool makers was "to adapt to the new intersectoral relationships required" (European Communities, 1983:10). Many of the most critical interactions involved firms and even industries which had not previously been directly linked. In such situations, action requires the ability to form linkages quickly, to share ideas and resources without having formed proven bonds of trust and long-term commitment.

Problem #2: Too Close. The traditional model portrayed in the management literature assumes that strong, long-lasting interfirm linkages are required for cooperative innovation involving users and suppliers. However, such a tightly-linked network is likely to be a poor source of new ideas in the first place. Mark Granovetter (1973) showed that weak ties between individuals are more important than strong ties for determining the rate of diffusion and the eventual spread of new ideas. The reason for this is deceptively simple: if interactions are always limited to those one already knows well, one is unlikely to come in contact with any very new ideas -- or to recognize their value if one does. As Granovetter found, "those to whom we are weakly tied are more likely to move in circles different from our own and will thus have access to information different from that which we (normally) receive" (p. 1371).

Further, the kind of novel information that is available through these

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loose connections is often sufficiently puzzling, anomalous, or surprising to arouse attention. To understand or interpret the new information, the actor must make sense of reality in new ways[2]. The development of the Japanese "just-in-time" system of production serves as an example. Americans have long enjoyed the convenience of self-serve supermarkets. They take the existence of this form of retailing for granted. However, when a Japanese production manager came in contact with this American phenomenon, he puzzled over what was to him a novel way of handling a bewildering variety of goods, one which ensured that the right item consistently was delivered to the right place on the shelf just as it was needed, with a minimum of planning. His puzzling led him to develop one of the major "Japanese" manufacturing innovations: the system of just-in-time production.

Similarly, during the 1970's Swiss machine tool makers moved far more swiftly and decisively into computer numerical controlled (CNC) equipment than did their British and American rivals, despite the lack of a major Swiss domestic market and a highly craft-based local economy (Ackermann and Harrop, 1985). One interpretation of this apparent anomaly is that the Swiss machine tool makers, without the luxury of being trusted home market suppliers, were forced to create weaker but more numerous and diverse relationships with user firms and other companies and institutions in a number of countries. Evidence suggests that during this period, while British and American machine tool makers focused on responding to the existing

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[2] As indicated above, information that is too divergent from existing cognitive maps or that is expressed in too foreign a language will likely be ignored. On the other hand, environmental cues which are "sufficiently different" are likely to be picked up (Kiesler and Sproull, 1982). Thus, neither very strong ties nor lack of any commonality across organizations is likely to be optimal for transferring new ideas.

demands of their home market customers, the Swiss firms were more aggressively exploring and utilizing a variety of technological developments world-wide (Ackermann and Harrop, 1985).

Further, organizations bear significant costs in building and maintaining long-lived, open, and trusting inter-firm relationships. First, interorganizational coordination is costly in terms of time and resources. Case-based research suggests that building trust among organizations is a slow, cyclical process requiring years of repeated transactions (O'Toole et al., 1972). And because close ties and shared understanding are produced by communication (Scheff, 1967; Olsen, 1978), the process is particularly costly in terms of human resources.

Second, maintaining close links with outside firms imposes costs because it decreases the organization's flexibility and autonomy (Thompson and McEwen, 1958; Evan, 1966; Terreberry, 1968). Close supplier-user relationships represent considerable investment in an existing set of technologies, capabilities, relationships, and even ways of thinking and talking about those technologies. While these investments can support incremental or even major innovations that build on the same set of inputs, they also preclude embracing new approaches. As Abernathy and Clark (1985) point out, technological innovation can obsolete existing external relationships just as it can threaten well-developed internal capabilities and assumptions. When this occurs, only firms that are willing to redefine their external arrangements will be able to make the transition.

However, organizations are frequently unable even to recognize the need

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to venture outside the bounds of familiar and comfortable interfirm arrangements. Well-developed linkages among companies in a particular sector constitute an "infrastructure (which) defines the boundaries of technological problems, provides an accepted technological approach, and establishes the criteria for evaluating projects and results" (Weiss and Birnbaum, 1989: 1020). The infrastructure further defines what kinds of information will be recognized and used by organizational decision-makers. Therefore while longstanding relationships facilitate certain kinds of innovation, they also lead to increasingly narrow definitions of the appropriate realm in which innovation can occur.

The costs of strong, well-developed ties between users and suppliers is apparent in an example from the steel industry. Examining the reasons for the rapid adoption of the new basic oxygen furnace (BOF) steelmaking technology in Japan, Lynn (1982) argues that the lack of strong links between the major machine and component suppliers and the Japanese steel companies allowed the latter to move more swiftly into the new technology. According to Lynn, these companies did not have to battle the entrenched interests of existing machine tool developers to develop the new areas of expertise required for BOF technology.

Problem #3: Too Static. In the traditional model of user-supplier cooperation, no provision is made for the fact that the nature of the cooperative relationship needs to vary according to the situation. Different problems, and different stages of a given problem, require different participants and different modes of communication among players. This finding appears to hold for the problems of innovation in R&D labs (Allen,

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1977; Allen, Lee and Tushman, 1980), in manufacturing operations (Tyre, 1990; Tyre and Hauptman, 1989), or in public service organizations (Clark, 1965; Van de Ven, 1980). Different tasks or activity phases need to be matched with appropriate participants and problem-solving strategies. Significantly, these can vary over the course of a single project or over the life of a technology.

Clark (1965), for instance, studied changes in educational institutions faced with significant technological and demographic shifts in their environments. In these situations innovations in education emerged not from specific interorganizational linkages but from evolving "interorganizational patterns of action" (p. 33). Different organizations participated in different stages of the change process, as appropriate to their different sets of interests and resources. Interorganizational agreements regarding the sharing of problems were often explicit, but were limited in time and scope. New agreements were formed at operating levels of the organizations as required by specific problem issues. Clark describes this process as a "rolling federation or alliance" in which "the decision resulted from the interaction of different parties at different stages" (p. 236).

Expanding the Organization's Domain: An Example from Printed Circuit Board Manufacturing

Recent events demonstrate how turbulent technological change can create the need to redefine the organization's domain and the terms of interorganizational cooperation. In 1989 U.S. electronics manufacturers were faced with a sudden and urgent need to reduce or eliminate the use of chlorofluorocarbons (CFCs) in their manufacturing processes. Even within

the fast-changing world of microelectronics, the speed with which the problem surfaced was unusual. The CFC issue, which had lain dormant for some 15 years, became a significant concern with the signing of the Montreal Protocol in September, 1987[3]. More alarming, in July of 1989, quotas and significant price increases were instituted for CFC113, then used in virtually all PC board cleaning applications. The issue moved to center stage for electronic assembly managers. Until that time, CFC113 had been considered a nearly perfect cleaning solvent: effective, inexpensive, nonflammable, and nontoxic to humans. The suddenness of the action and its impact on companies using CFC113 meant, as one participant expressed it, that "the time to do development in this area was compressed -- we had to do development in real time."

However, the appropriate objective of the development effort was far from clear. The Montreal Protocol specified stepped reductions in CFC usage; it did not require full elimination of CFCs in production. Yet even while companies were exploring possible stop-gap reduction possibilities, many users questioned the value of developing technologies which would reduce but not eliminate the emissions problem. Referring to other chlorine-based solvents which involved relatively minor changes in cleaning methods, one technical manager said,

> Why should we work on alternatives that just reduce the problem, and may add to other environmental concerns? Even if we reduce emissions of CFCs by 95%, that still leaves us with 5% of the problem -- and, at the rate this industry is growing, that could still be a very significant issue. With some so-called alternative chlorinated solvents we do not even know the magnitude of the potential problems, but we can guess

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[3] The Montreal Protocol, which was signed by the United States and 40 other countries, stipulated that countries would limit CFC utilization to 1986 levels by June of 1989, and would further reduce all use of CFC's by 50% by 1998.

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that they will lead to negative public reactions.

In addition, even before ozone protection became a major issue, concerns had been raised about the continued viability of current cleaning processes themselves. As leading companies in the industry moved to surface-mount components, two-sided boards, and increasingly fine spacing (or "pitch") between components, they questioned whether existing solvent-based cleaning processes would be able to remove excess solder flux and other debris from boards which, in the future, would be even more densely populated by electronic components. According a manager who had been intimately involved in his company's move into surface mount technologies,

> We are beginning to realize that one standard CFC-based process is not the only, best answer. We cannot even quantify the physical cleaning requirements of products now in design, but we do know that they are getting harder to clean. The whole CFC issue only forces us to face serious, disruptive change in cleaning technologies a lot sooner.

The problem of developing new cleaning processes was complicated by the number of possible solution approaches and the uncertainties surrounding each of them. For instance, many companies viewed assembly processes that did not require post-solder cleaning (i.e., "no-clean" operations) as the most complete solution to the cleaning issue. However, especially in surface-mount applications, "no-clean" operations would entail dramatic changes in soldering materials, equipment, and processes. "We really have no notion of how likely we are to succeed in developing no-clean surface mounting process," explained one participant, "or of how long it will take." At the other extreme, users and suppliers of cleaning equipment had begun to experiment with relatively minor modifications to existing machines to increase their ability to contain and recirculate the CFCs used in the cleaning process. And, while these modifications were not seen as permanent solutions, it was also unclear just how far fluid losses from existing machines could be reduced. Finally, a

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variety of alternative cleaning processes based on non-chlorine cleaning fluids were being discussed. These included terpene, aqueous, and alcohol-based technologies. Yet each of these possibilities raised questions which were not only difficult to answer but also difficult to investigate given current levels of knowledge. For instance, no tests had been developed for exploring the long-term corrosion or failure effects of these cleaning solutions on the printed circuit board. Similarly, flammability and/or pollution effects were a concern with each of the alternative cleaning processes, yet no one knew to what extent further development of the equipment would mitigate these problems.

Moving away from CFC-based solvents involved fundamental changes in materials, equipment, and methods of cleaning in semiconductor and printed circuit board production, yet traditional suppliers were offering few new solutions. Many electronics companies were becoming frustrated by months of false starts with traditional partners. According to a senior manager in charge of CFC reduction efforts at one U.S. company,

> We have been spending a great deal of effort working closely with both our solvent suppliers and manufacturers of cleaning equipment. I have begun to examine the linkages, and what I'm finding is that there are some critical holes in the fabric. Each of the companies involved brings knowledge relevant to its own products, processes, and raw material inputs. Their groundrules are determined by their specific areas of expertise and by the need to protect existing technologies and business segments. As a result, important aspects of the science and technology underlying this problem simply are not being addressed, or even recognized as relevant. The direction our suppliers are moving us in will result in a second-rate solution with fundamental underlying problems.

In response to these frustrations, new patterns of cooperation and interaction were beginning to form among suppliers and users in the industry. Many electronics producers had begun what one participant

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described as "a sort of mating dance": instead of sticking to traditional supplier relationships, PC board producers were beginning to widen their span of attention. Managers from major companies were touring the country and talking to a variety of existing and potential equipment and chemical producers in order to better understand the issues, the range of relevant technologies, and the diversity of responses and opinions. As one manager explained, "We need to redefine the issues -- the relevant equipment suppliers have to think like cleaning companies, not like makers of solvent cleaning equipment. Maybe we should be talking to people who make dishwashers!" Users who had traditionally purchased turn-key cleaning units were exploring advances in separate elements of the process, such as conveyors and safety equipment. While virtually all operations in the U.S. had sourced their cleaning equipment domestically before 1989, most large PC board producers were identifying and visiting European equipment and chemical producers to examine their different approaches.

With each player trying to sort out the market before proceeding, numerous new industry groups and informal linkages between companies were created. Managers came together in these forums to test their impressions and share viewpoints. Internally, the key questions being discussed began to shift from "what is the best solution to the CFC problem and how will we develop it?" to "given that we have not yet identified the right solution, what are the right linkages to develop to examine the question? What kinds of solutions are being considered, and how can we position ourselves to participate in unknown future developments?".

When firms face technological shifts, many of the basic resources which supported technical progress in the past are destroyed or obsoleted. Embedded technical systems are rendered inappropriate, and firms must develop new skills and new kinds of knowledge. In the process, technological shifts disrupt existing organizational and political systems within and among firms. New kinds of goals, values, and power relations are needed to support a new focus on a changed set of critical performance parameters. Further, because the new focus tends to shift the relevant domain of the organization, existing domain boundaries and rules regarding how to collect, filter, and interpret external stimuli will need to be altered (Kiesler and Sproull, 1982; Normann, 1971). Therefore such shifts "can be understood only in the context of the very complex interaction pattern between cognitive and political processes in organizations" (Normann 1971: 215).

At the same time, when technologies are shifting other aspects of the external environment are often changing and developing in unpredictable ways. The appearance of new players in an emerging technical field, new technical developments, and the emergence of new markets or applications all create a changing set of problems or opportunities for existing firms. For firms involved in the early stages of a technological shift, the "evolving new technology represents a widening stream of potential solutions" against a constantly changing background of problems, players, and choice opportunities (Lynn, 1982).

In such situations organizations must deal not just with uncertainty, but also with ambiguity. New information can have multiple, often conflicting interpretations that are difficult or impossible to analyze systematically. Appropriate goals and performance parameters are also open to conflicting or changing definitions. Even the relevant parties to discussion or negotiation are unclear, given rapid changes in the external environment and in the boundaries of the firm's relevant domain.

Ambiguity, therefore, requires the organization to be highly adaptive to changing conditions and alternative interpretations of events. It also demands that the organization be highly interactive. Research suggests that under such ambiguous conditions, clarity emerges only through considerable interaction and communication among players with differing views and interests (Daft and Lengel, 1986; Mintzberg et al., 1976). On the other hand, it is unlikely that firms will be able to rely on well-developed, long-standing linkages with outside organizations. Indeed, Terreberry (1968) points out that "it may well be that coordination per se, in the static sense usually implied by that term, is dysfunctional for adaptation to turbulent fields" (p. 605).

Instead, theory suggests that in order to cope with ambiguous, ill-defined technological shifts, organizations need to create linkage patterns which are **multi-stranded, reconstitutive, and political**[4]. "Multi-stranded" implies that linkage networks include many, diverse interests and perspectives and that the structure of such networks changes over time. "Reconstitutive" refers both to the need to reframe ill-structured problems

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[4] This set of attributes is adapted from Van de Ven's (1980b) program planning model, which calls for a problem solving process that is "incremental, reconstitutive, and political".

and to redefine interorganizational relationships. Finally, by saying that interaction patterns are political, I emphasize that solutions emerge from negotiation and competition among firms at least as much as from cooperation and trust.

Multi-Stranded Networks: According to Terreberry (1968), when an organization faces technological or other environmental shifts, "its constituents are a multitude of other formal organizations" (p. 600). Interdependencies among diverse organizations become more salient, making it necessary to view the organization as a "subsystem of a larger social system" (p. 601).

One reason for this is that technological shifts, by definition, require new skills, knowledge, and even ways of viewing the world. To respond, organizations need to "borrow parts of the specialist competence needed from the external environment" (Normann, 1971: 212). Forming links to new external (and internal) players with potentially relevant capabilities enables the organization to explore important new features of the technology and the environment, and to "map" these onto the new products and processes. According to Terreberry (1968), such "diversity in a system's input and output interdependencies will increase adaptability" (p. 612). Therefore, the organization may have to develop an expanded "information set" which is different from and wider than the group of organizations with which it normally exchanges material and resources (Terreberry, 1968).

In the traditional model of organizational cooperation, strong ties and the assumption of long-term relationships enable partners to work together from

the earliest stages of new development project (Hayes et al., 1988). However when problems are highly ambiguous, it is not clear at the outset which organizations and organizational subgroups should be involved. Even if their identities were known, involving all relevant parties at all stages of the problem solving process would lead quickly to cognitive and procedural overload (Van de Ven, 1980a). In a multi-stranded network, different sets of players are involved in different stages of problem definition and problem solving. Groups or organizations may enter, exit, and reenter the process according to the match between their interests or capabilities and emerging issues or problem phases (Van de Ven, 1980a). Thus interorganizational networks frequently resemble a "rolling federation or alliance" (Clark, 1965: 236) in which diverse organizations agree to share "problems, and hence domains of work, under limited agreements" (p. 234).

The temporary or exploratory nature of the linkages formed is an important aspect of the multi-stranded network. By forming temporary alliances, individuals gain exposure to outside parties and new ideas "without the threatening step of making them formal organization members" (Normann, 1971: 212), or even quasi-members. Metcalf (1981) describes such multi-stranded, loosely linked collaborative relationships as "precarious partnerships". He argues that the formation of such relationships opens up new avenues for innovation by creating new opportunities for experimentation, and by partially removing the experimentation process from normal bureaucratic oversight. "Detached temporarily from their established roles, and without committing their constituents, individuals drawn from the various publics can explore the consequences of untested strategies and alternative designs" (p. 514). Similarly, Normann (1971) argues that a

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temporary restructuring is often necessary to unfreeze existing organizational relationships and enable innovative action. Such restructurings have the effect of "decreasing the visibility and rigidity of power and status relationships and providing the individual with discretion and opportunities for undertaking activities without being observed or hindered" (p. 213).

Lanzara (1983) also describes the importance of creating experimental organizational linkages for dealing with unusual situations. He argues that when environmental shifts are massive and cannot be analyzed in traditional terms, effective responses often come from "ephemeral organizations". These exist outside of traditional bureaucratic structures and are explicitly temporary. Membership cuts across existing organizations; the boundaries of Lanzara's ephemeral organizations are "fuzzy" and vary as requirements change. The solutions developed by these temporary groupings often serve as models for adoption by more permanent organizational units. New solutions were often created by framing problems and applying existing knowledge in new ways. The ephemeral organizations studied by Lanzara borrowed familiar solutions for use in new contexts, or juxtaposed existing action programs in new ways. These experiments would not be feasible in more well-structured organizational settings. Instead, according to Lanzara, the temporary, unofficial status of ephemeral organizations provided members with a "zone of safety" or "zone of freedom" for approaching unusual problems in innovative ways. Further, permeable group boundaries and changing memberships enabled the groups studied by Lanzara to redefine problems and build new solutions as they progressed.

As noted by Lindblom (1965), "Multiplicity copes with the inevitability of

omission and other errors in complex problem solving" (p. 151). When
technologies are shifting, the right problems to focus on (let alone the right
solutions to aim for) are still undefined. Yet given limited resources, no
single firm can pursue all development paths. When organizations that have
chosen alternate definitions of the problem and its solution are linked but not
committed, the system as a whole can pursue multiple, parallel development
paths. Organizations can pool experiences and diverse interpretations of
confusing events (Putnam and Sorenson, 1982).

Reconstitutive Network Patterns: When technologies shift they often
require fundamental changes in the organization's human and technical
systems, procedures, goal structures and power relationships (Normann, 1971;
Leonard-Barton, 1988; Van de Ven, 1986). Significant shifts therefore require
new kinds of assumptions or "cognitive maps" to make sense of the world, as
well as new kinds of external relationships and interdependencies (Terreberry,
1968; Normann, 1971). Technological shifts obsolete established rules for
noticing events, for interpreting information, and even for bounding the
environment (Kiesler and Sproull, 1982; Normann, 1971).

Therefore important characteristics of the environment and of the
technological developments it calls for have to be created or "enacted",
rather than simply analyzed (Weick, 1979; Daft and MacIntosh, 1981).
Problem solving procedures and even problems themselves must be reinvented
or restructured to make ambiguous issues workable.

All of this implies that the organization itself must be redefined by its

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members as they struggle with change. The problem solving process must be reconstitutive of both the problem and of the organization and its linkages. New ways of interpreting events, measuring progress, and understanding the environment must emerge from action, rather than being available to guide action steps (Van de Ven, 1980a). As Thompson and McEwan (1958) point out, "purpose becomes a question to be decided, rather than an obvious matter" (p. 30).

Political Network Processes: Multi-stranded, reconstitutive network processes involve interactions among richly varied sets of actors with divergent interests and interpretations of events. Network interactions are therefore necessarily political in the sense that organizations are partisan: organizations with different perspectives on the future of the technology and the most promising approaches must fight to win legitimacy for their views and to convince organizations with complementary capabilities to help carry out their agendas (Benson, 1975). As Van de Ven (1986) points out, "Innovation... is a collective achievement of pushing and riding ideas into good currency. The social and political dynamics become paramount as one addresses the energy and commitment that are needed among coalitions of interest groups to develop an innovation" (p. 591). When technologies shift, there are no formal means for making optimal choices among ambiguous alternatives. Instead, the process is political. Influence and bargaining among partially cooperative but partially competing organizations shape the direction of technological innovation and adoption (Pfeffer and Salancik, 1978; Weiss and Birnbaum, 1989).

According to Aldrich and Whetten (1981), "The field (of organizational

networks) has been dominated by an orientation favoring coordination, which has deflected attention away from the systematic study of critical network processes such as conflict, struggles for power, exploitation, and protection of autonomy" (p. 404). Yet these processes appear to be central to the ability of organizations to recreate and reorder their worlds under conditions of significant technological shifts.

Arguments, power struggles, and differences of opinion are not necessarily devisive but can help to create a new technological community. Multiple interactions and exchanges with a diverse set of external actors allow the organization to explore new aspects of the environment, to test a new set of external constraints, and to define its new operating domain and create and fill a distinct organizational niche within it (Aldrich and Whetten, 1981; Pfeffer and Salancik, 1978). They allow organizations to define distinct roles or areas of specialization within a new technical area (Wievel and Hunter, 1985) and to renegotiate their dependency relationships with each other (Normann, 1971). Firms can test alternate definitions of their own organizational and domain boundaries, and in the process of testing alter their understanding of how boundaries are set and reset. As their roles evolve, apparent competitors can become important sources of scarce inputs such as ideas, people, and know-how (Wievel and Hunter, 1985; von Hipple, 1988). By forming various exploratory or experimental relationships over time, the organization has the opportunity to observe and to model new ways of defining technological issues and new approaches to technological problem solving before committing to them.

Further, conflicts help to define new rules or expectations for

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interaction within a network; as differences are surfaced and at least partially resolved, "harmony (develops) through the very feuding which segments" different groups (Gerlach and Palmer, 1981: 326). In technological communities, harmony often takes the form of emerging technical standards which support further developments and diffusion. Arguments also reveal competing assumptions and interpretations of events, often forcing participants to examine their own basic concepts in light of alternative formulations. As Van de Ven (1986) notes, "conflict and debate between advocates of competing perspectives...leads to reconsideration of the organization's mission, and perhaps a reformulation of that mission" (p. 603).

Two Models of Technical Collaboration

The foregoing suggests that it is   to consider two very different models of interfirm collaboration arrangements. The first, which I have called the traditional model, involves a few tight linkages among carefully selected partners. Because coordination between customers and their suppliers is based on trust, relationships are developed and maintained over relatively long periods of time. The second model describes a relatively fluid set of network arrangements. Interfirm relationships are multiple, temporary, and overlapping. Members enter into relationships in order to explore new technical possibilities, reframe existing technical problems, or expand the experimental capacity of the firm. An important aspect of interactions in the fluid model is their political character. While firms trade information and ideas, they are simultaneously "pushing and riding (their) ideas into good currency" (Van de Ven 1986: 591).

These two models of technical collaboration are summarized in Exhibit 1. One emergent hypothesis from this discussion is that the traditional model describes a set of relationships that is effective for carrying out innovations which build on existing assumptions about the firm, the environment, and the manufacturing process. High levels of familiarity and commitment allow partners to exchange information freely and easily, facilitating the development process when technical problems are complex or require small but continuous improvements over time. On the other hand, this paper has argued that when technologies are shifting, the fluid model of network interactions is more appropriate. In this model, innovation and experimentation are maximized by the interaction of multiple firms with diverse interests, capabilities, and world views. Overlapping, temporary alliances create the opportunity to redefine available options by recombining skills, knowledge, and resources. Meanwhile, competition for resources, ideas, and acceptance among multiple organizations and coalitions maximizes the level of activity and forward momentum in the system.

Exhibit 1

TWO MODELS OF TECHNICAL NETWORK PATTERNS

FLUID MODEL (TECHNOLOGICAL UPHEAVALS)	TRADITIONAL MODEL (TECHNOLOGICAL REFINEMENTS)
MANY, LOOSE LINKAGES;	FEW, CLOSE PARTNERS;
EACH ALLIANCE INCLUDES MULTIPLE COMPANIES;	DYADIC PARTNERSHIPS;
OVERLAPPING MEMBERSHIP CREATES REDUNDANCY;	MEMBERSHIP BASED ON COMPLEMENTARY CAPABILITIES IS EFFICIENT;
TEMPORARY, SHIFTING, EXPLORATORY LINKAGES;	LONG-TERM RELATIONSHIPS INVOLVE HIGH COMMITMENT ON BOTH SIDES;
BLURRED BOUNDARIES DUE TO OVERLAPPING AND SHIFTING MEMBERSHIP MEANS THAT IDEAS FLOW THROUGHOUT THE SYSTEM;	PARTNERS PROTECT PROPRIETARY TECHNOLOGY AND NEW IDEAS;
PARTNERS BRING DIFFERENT INTERESTS, LANGUAGES, AND ASSUMPTIONS;	PARTNERS SHARE COMMON LANGUAGE AND INTERESTS;
POLITICAL PROCESSES DOMINATE: INFLUENCE, NEGOTIATION, COALITION FORMATION;	COLLABORATIVE PROCESS BASED ON TRUST, LONG-TERM INVESTMENTS;
PROBLEM SOLVING UNDER AMBIGUITY:	COMPLEX PROBLEM SOLVING;
WORK THE PROBLEM AT SEVERAL LEVELS, IN SEVERAL DIRECTIONS SIMULTANEOUSLY;	ADDRESS PROBLEMS IN SYSTEMATIC, TOP-DOWN FASHION;
REFRAME THE PROBLEM/ SOLUTION/ENVIRONMENT: NEW JUXTAPOSITION OF EXISTING COMPONENTS.	TEST AND REFINE HYPOTHESES, SOLUTION ALTERNATIVES REQUIRES TIGHT COORDINATION.

This paper is intended to provoke interest in an alternative model of interfirm technical collaboration. However, many aspects of that model are still to be developed. One of the unanswered questions concerns the mechanisms by which fluid partnerships are created, developed, and changed. Existing research suggests that interfirm sharing at the idea level requires a long history of more tentative interactions (O'Toole, 1972; Van de Ven and Walker, 1984); we do not yet know how firms can develop temporary, exploratory linkages or what factors support sufficient communication across dissimilar partners. Existing literature on fluid network patterns among individuals may provide a fruitful starting point for research on this question. For instance, Granovetter's (1973) research suggests that loose linkages among individuals are often based on strong ties that have weakened through disuse over time, such as the long-lived but distant links among old college classmates. Such lasting linkage mechanisms have often been noted, for instance, as an enabling factor behind the ability of Japanese managers at competing firms to collaborate on technical questions. An alternate view, however, suggests that loose interfirm linkages are based on infrequent but continuing contact. For instance, in describing some of the loose linkage patterns in the electronics industry, one observer noted, "At one major company, the longest contract you can get as a supplier is only 9 months. But if you don't get the next contract, it's not as if they stop talking to you -- you're never totally out of the game."

Another set of questions concerns the contingent usefulness of fluid networks and their interaction with the organization's long-term commitments.

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The optimal mix of tight, close network relationships and loose, diverse ones is expected to vary over time, depending on the external situation and the nature of the challenges facing the organization (Gerlach and Palmer, 1981). This paper suggests that the network patterns adopted to create new technical possibilities during turbulent periods are likely to be quite different from those needed for solving remaining problems. This is consistent with existing theory (e.g. Abernathy and Utterback, 1978; Pfeffer and Salancik, 1978). However most existing theory suggests some variant of the life cycle theme, wherein periods of turbulent technological change are typically followed by episodes of more normal, orderly development based on the new agendas laid down. Reality, on the other hand, suggests that technological evolution is not so well-mannered. A given firm encompasses a large, interdependent and interrelated set of production technologies at different stages of development and facing unique environmental forces. The amount and nature of change involved in each one may vary unpredictably over time. However, it is uncertain whether temporary, shifting alliance patterns can survive alongside long-lived, dyadic partnerships (Lanzara, 1983). Indeed, a danger noted in this paper is that in concentrating on building increasingly smooth interorganizational relationships, firms will neglect the confusing, inefficient, often uncomfortable exploration processes required to create new opportunities.

A related problem concerns the protection of proprietary technology in fluid technical networks. Overlapping and shifting membership patterns will tend to create an open and even unmanaged flow of information across companies. One possibility is that firms will need to learn how to share selectively and how to identify critical areas of proprietary technology. Another possible answer is that organizations will need to reformulate their

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notions about how they create long-term competitive advantage. When interfirm relationships are fluid, success may depend not on proprietary knowledge but on the ability to transfer and absorb new technologies, to rapidly turn new ideas into testable prototypes, and to design the evolving design process and the changing organization.

Finally, very little is known about the micro processes of problem solving within a multi-stranded, reconstitutive, political network. This paper has suggested that the process resembles a garbage-can model of decision making (March, Cohen, and Olsen, 1972). However it is also possible that the problem solving process, though highly experimental, displays certain patterns as to the nature of the experiments performed, the allocation of tasks within the network, and the political forces that determine technological outcomes. Understanding these patterns is required if we are to begin to understand the role of management in a fluid, seemingly unmanageable technical network.

Answers to these and other questions will take time. They require that researchers examine not just the form but also the content and process of interfirm interactions under conditions of technological change (Aldrich and Whetten, 1981; Ancona, 1990). Therefore, further research is likely to demand multi-method approaches and innovative research designs. If successful, such efforts promise both to improve our understanding of the management of innovation and to enrich our theories of organizations and their evolution.

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